ACTIVE TRACKING OF ROTATIONAL MODE HELIOSTAT

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Dedicate to my beloved mother

Madam Yew Siow Lan,

And

My beloved father.

May He rest in peace in Heaven.

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ABSTRACT

Active tracking methods for rotational mode heliostat invented by Prof. Dr. Y. T. Chen recently, are proposed in this thesis. This is to provide an alternative tracking method for Non-Imaging Focusing Heliostat (NIFH) designed by UTM that is simple and cost effective, with reasonable performance. The newly developed methods consist of two parts: primary tracking and secondary tracking. For primary tracking, a sensor plane, which is built up of a gnomon surrounded by eight photo-detectors, is used to detect the deviation of incident angle of incoming sunray. In principle, the normal of the sensor plane should always point towards the direction of the sun. The displacement of the incoming sunray will be sensed by comparing the intensity difference of the photo-detectors, as the gnomon will cast a shadow onto a portion area of photo-detectors' surface. The proposed tracking method is autonomous and stand-alone. The entire sensing and motor-controlling task is performing by using a simple electronic circuit, attached on the body of the heliostat. No complicated computer software control is needed. In addition, open-loop clock-like signal will be fed into the system to further increase the speed of error compensation and for better stability performance. For secondary tracking, the use of mechanical cam drive by consistent clock is proposed. From the study of NIFH's tracking equation, a high-precision mechanical cam is proposed to compensate the aberration of slave mirror throughout the tracking day. The merits of these methods are the larger range of dynamic range for the sensors and their simple designs.

ABSTRAK

Satu penjejakan secara aktif bagi heliostat mod putaran baru adalah dicadangkan. Konsep utama rekabentuk ini adalah supaya memberi satu pilihan alternatif bagi heliostat mod putaran baru yang mempunyai cara penjejakan yang mudah dan kos-efektif, dengan prestasi yang munasabah. Cara baru ini boleh dibahagikan kepada dua bahagian: penjejakan 'cermin-tuan' dan penjejakan 'cermin-hamba'. Bagi penjejakan 'cermin-tuan', satu tapak pengesan dibina dengan satu rod dikelilingi dengan lapan diod sensitif cahaya, digunakan untuk mengesan sudut tuju cahaya matahari. Secara prinsipnya, rod tersebut seharusnya menuju ke arah matahari sepanjang masa penjejakan. Dengan membanding kekuatan cahaya matahari yang diterima oleh foto-diod, sudut tuju cahaya matahari dikesan. Semua kerja pengesanan dan kawalan motor adalah dijalankan dengan menggunakan litar elektronik yang mudah. Penjejakan secara aktif tidak memerlukan bantuan komputer. Isyarat gelung litar buka dalam bentuk jam ditambahkan ke dalam sistem untuk mencepatkan kerja penbetulan posisi dan juga untuk prestasi kestabilan yang lebih baik. Bagi penjejakan 'cermin-hamba', 'cam' mekanikal dipandu dengan jam dicadangkan. Dari formula penjejakan Non-Imaging Focusing Heliostat (NIFH), 'cam' mekanikal dengan kejituan yang tinggi dicadangkan untuk membetulkan posisi 'cermin-hamba' semasa penjejakan. Kebaikan cara penjejakan baru ini adalah rekabentuknya yang ringkas dan julat-dinamik yang luas.

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LIST OF SYMBOLS

Φ	-	Latitude
ϕ	-	Facing angle of the Non-Imaging Focusing Heliostat
λ	-	Target angle of the Non-Imaging Focusing Heliostat
β	-	Altitude angle in the coordinate system attached to the Non-Imaging Focusing Heliostat
θ	-	Incidence angle of the Non-Imaging Focusing Heliostat
ρ	-	Rotation angle of the Non-Imaging Focusing Heliostat
σ	-	Horizontal tilting angle of the Non-Imaging Focusing Heliostat
γ	-	Vertical tilting angle of the Non-Imaging Focusing Heliostat
A	-	Gain
a	-	Area shaded by shadow on surface of photo-diode
d	-	Distance between two reflected image at target
f	-	Frequency
J_L	-	Light current density at a given intensity
L	-	Distance between the Non-Imaging Focusing Heliostat and a target
NIFH	-	Non-Imaging Focusing Heliostat
R	-	Resistance
UTM	-	Universiti Teknologi Malaysia
V	-	Voltage

CHAPTER I

INTRODUCTION

1.1 Introduction

Heliostat is a device consisting of mirrors revolved slowly occupying a tracking mechanism so as to reflect the sunray continuously in a fixed direction, onto a fixed target. Normally a second stage concentrator will be placed at the target, for better solar energy concentration usage.

In order to maintain their high performance in concentrating solar power systems, a heliostat must track the sun position with a high degree of accuracy. Various forms of tracking mechanisms, varying from simple to complex have been proposed. They are mainly mechanical or electrical/electronic system. Generally, the electronic system can exhibit better reliability and tracking accuracy. These include motors controlled electronically by various sensors, which detect the magnitude of solar illumination. A complex tracking system generally use computer-controlled motors with feedback or exhibiting fuzzy logic control.

Conventionally, an azimuth-elevation tracking mode heliostat is more common. Prof. Dr. Y. T. Chen and Prof. Dr. T. P. Bligh, had proposed a new rotation-elevation tracking mode heliostat [3], called Non-Imaging Focusing Heliostat (NIFH). New-rotational mode heliostat can perform sun tracking and sunlight focusing concurrently. The idea of using reflecting panels array to concentrate solar radiation can be traced back to BC212 firstly proposed by Archimedes. In the early history of heliostat's development, it was mostly use in astronomy field for solar observation. It was also used to study other celestial bodies and for spacecraft instrument calibration. In solar energy research field, heliostat has been applied mostly in the high temperature solar furnace and solar power station.

The active tracking of new rotational mode heliostat demonstrates a new tracking method for tracking the sun radiation and reflecting it onto a stationary target. This new tracking method will locate the incoming sunray automatically and respond to its changes.

This newly developed method can be separated into two parts: Primary tracking and secondary tracking. Primary tracking of the heliostat in active mode is a close loop control system while secondary tracking is an open loop control system. Closed-loop primary tracking, that is the master frame tracking of heliostat, is accomplished by using photo sensors to sense the displacement of the incoming sunray's incident angle and compensate the error by a feedback system. In the earth's frame, the sun appears to move across the sky as the earth rotates around the sun. The master frame of the heliostat will respond to this movement and counteract it. The result is that, when aligned properly, the reflection of the sunrays remains at the same location all day.

As compliment, a simple cam is proposed to accomplish the task for secondary slave-mirror tracking. The rotation of the secondary slave mirror through out the day is comparatively small. Thus a specially designed cam based on the formula derived by Prof. Dr. Y. T. Chen [3], driven by a clock, will be proposed for the secondary slave-mirror tracking. This is purely an open-loop control as there is no mechanism for sending feedback signal back to the control system.

The merits of these methods are larger dynamic range and their simpler designs. These new designs will further reduce the cost of fabrication of a heliostat and contribute to accelerate the development of solar energy industry..

To validate the feasibility of the design, the active primary tracking mechanism was tested with the first prototype of NIFH at the University of Technology Malaysia.

1.2 Scope of study

The scope of study includes accomplish the idea of active tracking of new-rotational mode heliostat. This project will cover the primary master-frame tracking while the secondary slave-mirror tracking is presented as suggestion for future works.

1.3 Research Objective

The main objective of the project is to design the mechanism of active tracking mode heliostat and test the feasibility of the tracking system by modifying the first prototype of Non-Imaging Focusing Heliostat, located at UTM, to an active tracking mode heliostat. The accuracy and stability of tracking system will be analyse for future development usage. The project also aims to propose an idea for the secondary slave-mirror tracking in active mode.

1.4 Thesis Overview

The first chapter of this thesis gives an overview of the research and clarify the objectives and scope of study. It is followed by chapter two, which overviews the Non-Imaging Focusing Heliostat (NIFH). Principles of tracking motion and the design of the first prototype of NIFH is also reviewed in this chapter.

Chapter three introduces the proposed active tracking method for new-rotational mode heliostat. The fundamental concept of the active tracking mechanism will be discussed. Tracking methodology and design of the active tracking system for new-rotational mode heliostat will also be included. The electronic circuits and mechanical designs for the required parts will be explained in this chapter too.

The following chapter will explain the system setup of active tracking mode NIFH. Constructions of the mechanical parts are illustrated. Configuration active tracking system on first prototype of NIFH is explained in this chapter too.

Results and the analysis of the active tracking system are discussed in chapter five. Tracking results of the experiment carried out is presented here. Analysis of the data on accuracy, stability and other aspects are discussed. Causes that contribute to tracking error are also identified at the end of this chapter.

Chapter six concludes the thesis with a summary and discussion on the limitations of the system. The complimentary proposed idea for active secondary slave mirror tracking is included in this chapter as suggestion for future work.